

Research Report
KTC-08-24/KH54-06-1F

STRUCTURAL EVALUATION OF THE JOHN A. ROEBLING SUSPENSION BRIDGE

by

Ching Chiaw Choo

Post-doctoral Research Fellow, Kentucky Transportation Center
Department of Civil Engineering
University of Kentucky

and

Issam E. Harik

Professor of Civil Engineering and Program Manager, Structures and Coatings Section,
Kentucky Transportation Center
University of Kentucky

Kentucky Transportation Center
College of Engineering, University of Kentucky

in cooperation with

Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U.S. Department of Transportation

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Kentucky, the Kentucky Transportation Cabinet, nor the Federal Highway Administration. This report does not constitute a standard, specification or regulation. Manufacturer or trade names are included for identification purposes only and are not to be considered an endorsement.

July 2008

Technical Report Documentation Page

1. Report No. KTC-08-24/KH54-06-1F		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle STRUCTURAL EVALUATION OF THE JOHN A. ROEBLING SUSPENSION BRIDGE				5. Report Date July 2008	
				6. Performing Organization Code	
				8. Performing Organization Report No. KTC-08-24/KH54-06-1F	
7. Author(s): Ching Chiaw Choo and Issam Harik					
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, Kentucky 40506-0281				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. KH 54	
				13. Type of Report and Period Covered Final	
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, Kentucky 40622					
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Kentucky Transportation Cabinet and the U.S. Department of Transportation, Federal Highway Administration.					
16. Abstract <p>The primary objective of the structural evaluation of the John A. Roebling Bridge is to determine the maximum allowable gross vehicle weight (GVW) that can be carried by the bridge deck structural elements such as the open steel grid deck, channels, standard sections, or built-up sections. To achieve this objective, four levels of analysis are carried out: "Element Level", "Sectional level I", "Sectional level II", and "Global level" analysis.</p> <p>The four levels of analysis yield a load envelope that encapsulates the maximum and minimum allowable loads. The maximum allowable gross vehicle weight (GVW) for different truck and bus types are presented for different levels of structural elements sectional loss. The loss or reduction in element sectional properties is due to rust, cracks, etc.</p> <p>The "Element Level Analysis" is the most critical and yielded the maximum allowable gross vehicle weights. The critical member in the bridge deck is the built-up 36 inch deep section. Its allowable bending strength controls the maximum "Gross Vehicle Weight" (GVW) that can be permitted on the bridge. Results are presented for different levels of sectional losses (10% to 40%, in 10% increments).</p> <p>In the event that replacement of the open grid deck will take place in the future, results are presented for different deck weights (10 psf to 50 psf in 10 psf increments). The current open grid deck weight is 20 psf.</p>					
17. Key Words Suspension Bridge, Structural Evaluation, Bending Capacity, Shear Capacity, Truck, Bus, Weight Limit			18. Distribution Statement Unlimited with approval of Kentucky Transportation Cabinet		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 60	
				22. Price	

EXECUTIVE SUMMARY

The primary objective of the structural evaluation of the John A. Roebling Bridge is to determine the maximum allowable gross vehicle (truck or bus) weight (GVW) that can be carried by the bridge deck structural elements: steel grid decking, channels, standards, and/or built-up members. The John A. Roebling Bridge carries KY 17 over the Ohio River between Covington, KY, and Cincinnati, OH. A detailed evaluation of the load carrying capacity of the cables and truss elements was completed in 2003 (Report No. KTC-03-10/MSC97-1F). In the present study four levels of analysis are carried out in order to capture the full load capacity spectrum:

i) Element Level Analysis

At this level of analysis, the bridge deck structural elements are analyzed independent of each other. Each element is assigned a specific tributary area, and the element support conditions are idealized as appropriate (i.e., simple, fixed, etc.).

ii) Sectional Level Analysis I

A three-dimensional structural model of the bridge deck is generated for this level of analysis. The model represents a portion of the real structure. A rule of length-to-width ratio (L/W) equal to a minimum of three (3) is applied. The width of the roadway is 31'-4". As a result, seven spans of 15'-0" each are used to produce a length-to-width ratio of slightly over three. The cable supports are idealized as simple supports.

iii) Sectional Level Analysis II

Three-dimensional models for the main span (approximately 1,100-ft in length) and the approach spans (approximately 300-ft in length each) are generated at this level of analysis. Primary cables and secondary suspenders are included in the models. The supports of the primary cables are idealized as simple supports at the towers and the end anchorages.

iv) Global Level Analysis

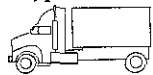
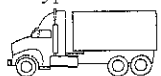

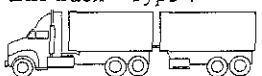
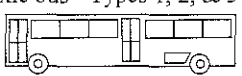
At this level of analysis, a three-dimensional model of the entire bridge is generated.

Throughout the investigation, four truck types and three bus types are considered. In 2007, the posted weight limits on the bridge were 17 tons for two-axle trucks and 22 tons for three-, four-, and five-axle trucks.

The "Element Level Analysis" yielded the critical maximum allowable gross vehicle weight (GVW) and the built-up member is the critical member.

The maximum allowable GVWs for trucks and buses are presented in Table E.1; values presented are those obtained from the *Element Level Analysis*.

Table E.1. Allowable Gross Vehicle Weight (GVW) in Tons for Different Percentages of Sectional Losses in the Built-Up Member

Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	20.17 tons	15.61 tons	11.04 tons	7.68 tons	4.80 tons
3-axle truck – Type 2 	21.52 tons	16.65 tons	11.78 tons	8.19 tons	5.12 tons
4-axle truck – Type 3 	24.09 tons	18.64 tons	13.19 tons	9.17 tons	5.73 tons
5-axle truck – Type 4 	36.68 tons	28.38 tons	20.08 tons	13.97 tons	8.72 tons
2-axle bus - Types 1, 2, & 3 	26.50 tons	20.50 tons	14.51 tons	10.09 tons	6.30 tons

* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

In the event that replacement of the open grid deck will take place in the future, results are presented for different deck weights (10 psf to 50 psf, in 10 psf increments) in Chapters 5, 6, 7, and 8, respectively, in accordance with the different levels of analysis. The current open grid deck weight is 20 psf.

ACKNOWLEDGEMENTS

The financial support provided by the Kentucky Transportation Cabinet (KyTC) is greatly appreciated. The authors would also like to thank the assistance of Mr. Robert Hans (KyTC-D06), Mr. Tom Schomaker (KyTC-D06), and Mr. David Steele (KyTC-Division of Maintenance). In addition, the authors would like to express their gratitude to Mr. Andrew C. Aiello, Assistant Director - Communications & Development of the Transit Authority of Northern Kentucky (TANK), for providing information regarding the bus types.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	i
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	viii
1 INTRODUCTION	1
1.1 The John A. Roebling Bridge	1
1.2 Research Objective and Scope	2
2 CAPACITY EVALUATION OF EXISTING STRUCTURAL ELEMENTS	3
2.1 Steel Decking	3
2.2 Steel Channels (C)	5
2.3 Steel Standard (S)	6
2.4 Steel Built-up Members	6
3 BRIDGE LOADING	8
3.1 Self-weight Loads	8
3.2 Live Loads	8
3.1.1 Truck Types	8
3.1.2 Bus Types	8
3.3 Assumptions	8
4 ELEMENT SECTIONAL LOSSES AND STRENGTH CAPACITY LOSSES	11
5 ELEMENT LEVEL ANALYSIS	13
5.1 Structural Idealization	13
5.1.1 Steel Decking	13
5.1.2 Steel Channel Section	13
5.1.3 Steel Standard Section	13
5.1.4 Built-up Section	15
5.2 Maximum Allowable Gross Vehicle Weight (GVW)	15
5.2.1 Maximum Allowable GVW on the Steel Decking	15
5.2.2 Maximum Allowable GVW on the Steel Channel Sections	15
5.2.3 Maximum Allowable GVW on the Steel Standard Sections	16
5.2.4 Maximum Allowable GVW on the Steel Built-up Sections	16
5.3 Critical Member for determining the GVW	16
5.4 Sample Calculations for the Gross Vehicle Weight GVW Limit	16
5.4.1 Tributary Width, Length, and Area	16
5.4.2 Dead Loads	16
5.4.3 Live Loads	17

5.4.4	Bending Moments	18
5.4.5	Allowable GVW Calculation	19
5.5	Allowable Gross Vehicle Weight (GVW) for Trucks and Buses	20
5.6	Allowable Gross Vehicle Weight (GVW) for Different Deck Weights	21
6	SECTIONAL LEVEL ANALYSIS I	26
6.1	Structural Idealization	26
6.2	Assumptions	26
6.3	Allowable Gross Vehicle Weight (GVW) for Trucks and Buses	26
6.4	Allowable Gross Vehicle Weight (GVW) for Different Deck Weights	28
7	SECTIONAL LEVEL ANALYSIS II	34
7.1	Structural Idealization	34
7.2	Assumptions	35
7.3	Allowable Gross Vehicle Weight (GVW) for Trucks and Buses	35
7.4	Allowable Gross Vehicle Weight (GVW) for Different Deck Weights	36
8	GLOBAL LEVEL ANALYSIS	41
8.1	Structural Idealization	41
8.2	Assumptions	41
8.3	Allowable Gross Vehicle Weight (GVW) for Trucks and Buses	41
8.4	Allowable Gross Vehicle Weight (GVW) for Different Deck Weights	43
9	SUMMARY AND CONCLUSIONS	48
	REFERENCES	50

LIST OF TABLES

Table 2.1.1	Load table for IDSI steel decks (2004)	5
Table 2.2.1	Flexural and shear capacity of the C10x20 channel section	6
Table 2.3.1	Flexural and shear capacity of the S15x50 standard section	6
Table 2.4.1	Flexural and shear capacity of 36-in built-up member	7
Table 3.1	Trucks traversing the Roebling Bridge	9
Table 3.2	Buses traversing the Roebling Bridge	10
Table 4.1	Effect of 10%, 20%, 30%, 40%, and 50% sectional loss on the sectional properties and capacities of the 36" built-up member	12
Table 5.4.1	Fraction of gross vehicle weight, ξ , attributed to the rear axle(s)	18
Table 5.5.1	Element Level Analysis - Allowable Gross Vehicle Weight (GVW) in Tons for Different Percentages of Sectional Loss in the Built-Up Member	20
Table 5.6.1	Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf	21
Table 5.6.2	Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf	22
Table 5.6.3	Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf	23
Table 5.6.4	Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf	24
Table 5.6.5	Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf	25
Table 6.1	Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member	28
Table 6.4.1	Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf	29

Table 6.4.2	Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf	30
Table 6.4.3	Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf	31
Table 6.4.4	Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf	32
Table 6.4.5	Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf	33
Table 7.1	Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member	35
Table 7.4.1	Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf	36
Table 7.4.2	Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf	37
Table 7.4.3	Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf	38
Table 7.4.4	Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf	39
Table 7.4.5	Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf	40
Table 8.1	Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member	42
Table 8.4.1	Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf	43
Table 8.4.2	Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf	44
Table 8.4.3	Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf	45
Table 8.4.4	Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf	46

Table 8.4.5	Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf	47
Table 9.1	Allowable gross vehicle weight (GVW) in tons for different percentages of sectional losses in the built-up member	49

LIST OF FIGURES

Figure 1.1	The John A. Roebling Bridge carries KY 17 over the Ohio River between Covington, KY, and Cincinnati, OH	1
Figure 1.2	Structural elements of the John A. Roebling Bridge	2
Figure 2.1	Structural elements of the bridge deck	3
Figure 2.1.1	Steel grid decking manufactured by Interlocking Deck Systems International (IDSI), Inc (2004)	4
Figure 2.1.2	Sectional properties of the IDSI's deck with 6-in main rail spacing (2004)	4
Figure 2.2.1	Properties of a C10x20 channel section	5
Figure 2.3.1	Properties of a S15x50 standard section	6
Figure 2.4.1	36-inch built-up member	7
Figure 5.1.1	Idealization of steel decking for the Element Level Analysis	13
Figure 5.1.2	Idealization of steel channel (C) for the Element Level Analysis	14
Figure 5.1.3	Idealization of steel standard (S) for the Element Level Analysis	14
Figure 5.1.4	Idealization of 36-in deepbuilt-up member	15
Figure 5.4.1	Loadings on 36-in built-up section	17
Figure 5.4.2	Moment due to dead loads	18
Figure 5.4.3	Moment due to truck or bus loads	18
Figure 6.1	Structural idealization of Sectional Level Analysis I	26
Figure 6.2	Structural model for Sectional Level Analysis I	27
Figure 7.1	Structural model of the main span for Sectional Level Analysis II	34

Figure 7.2	Structural model of the approach span for Sectional Level Analysis II	34
Figure 8.1	Structural model for Global Level Analysis	41

1 INTRODUCTION

1.1 THE JOHN A. ROEBLING BRIDGE

Completed in 1867, the John A. Roebling Bridge (Fig. 1.1) – formerly the Covington-Cincinnati Suspension Bridge – was the first permanent bridge to span the Ohio River between Kentucky and Ohio. In 1975, the bridge was designated as a National Historic Civil Engineering Landmark by the American Society of Civil Engineers and was listed on the National Register of Historic Places.

The John A. Roebling Bridge carries KY 17 over the Ohio River between the two aforementioned cities. The bridge is a three-span bridge. The main span of the bridge is approximately 1,100-ft long, carrying a two-lane 28-ft wide roadway. The two approach spans are approximately 300-ft long; the entire superstructure is thus approximately 1700-ft long. In addition, the bridge also carries an 8-ft 6-inch wide sidewalk cantilevered from both sides of the superstructure. The roadway is supported by a steel grid decking system, structural channel (**C**) sections, structural standard (**S**) sections, and built-up I-shaped plate girders. The roadway structural system is in turn supported by planar trusses, secondary suspenders, and primary cables. In 2007, the bridge's weight restrictions are posted as 17 tons for two-axle trucks and 22 tons for three-, four-, and five-axle trucks. Numerous structural truss and floor system repairs had been made in the past, with the latest one in the early 1990s.



Fig. 1.1 – The John A. Roebling Bridge carries KY 17 over the Ohio River between Covington, KY, and Cincinnati, OH.

1.2 RESEARCH OBJECTIVE AND SCOPE

The objective of this study is to conduct a structural evaluation of the John A. Roebling Bridge in order to determine the maximum allowable gross vehicle weight (GVW) that can be carried by the bridge deck structural elements shown in Fig. 1.2 (i.e., open steel grid decking, channel sections, standard sections, and built-up sections).

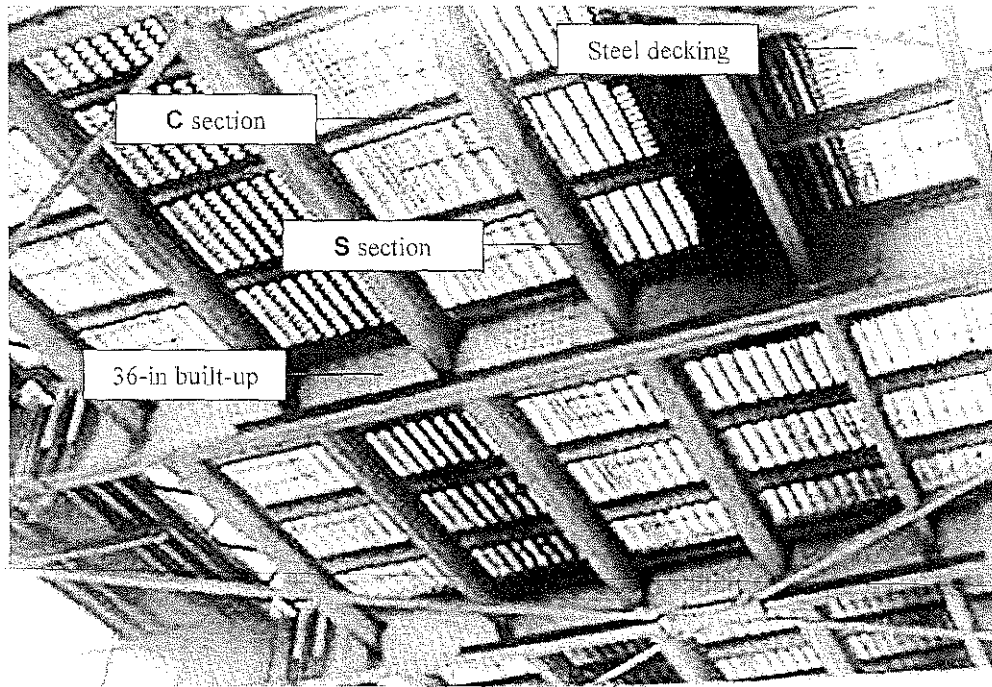
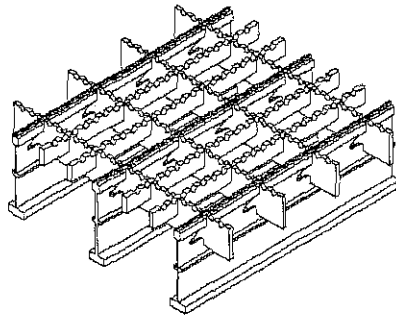


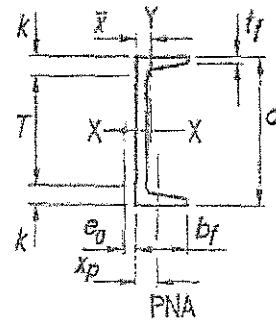
Fig. 1.2 – Structural elements of the John A. Roebling Bridge

2 CAPACITY EVALUATION OF THE BRIDGE DECK ELEMENTS

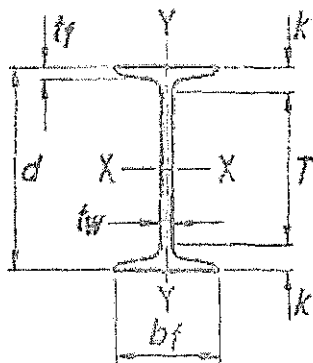
The bridge deck consists of the following four (4) structural components: open steel grid decking system (Fig. 2.1.a), structural channel (**C**) section (Fig. 2.1.b), structural standard (**S**) section (Fig. 2.1.c), and built-up I-shaped plate girder (Fig. 2.1.d).



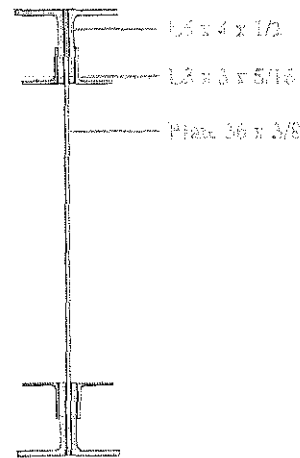
(a) 5-inch steel deck



(b) Channel (**C**) section



(c) Standard (**S**) section



(d) 36-inch built-up section

Fig. 2.1 – Structural elements of the bridge deck.

2.1 STEEL DECKING

The capacity of the existing open steel decking was determined by comparing the existing deck to a similar type of commercially available steel decking. The dimensions of the existing steel decking were measured to be 5-1/4" in height with main rails spaced 6-in center-to-center.

One commercially available open steel grid decking manufactured by the Interlocking Deck Systems International (IDSI), Inc. (2004), was found to be comparable to the existing steel decking. The main rail of the IDSI's steel decking has a height of 5-3/16", as shown in Fig. 2.2.1.a. A complete steel grid decking system (Fig. 2.2.1.b) may consist cross bars in the two perpendicular directions, main rails in the traffic direction, and reinforcing bars (not shown) in the transverse direction. Section properties of the IDSI's steel decking with main rails spaced at 6-in center-to-center are presented in Fig. 2.2.2.

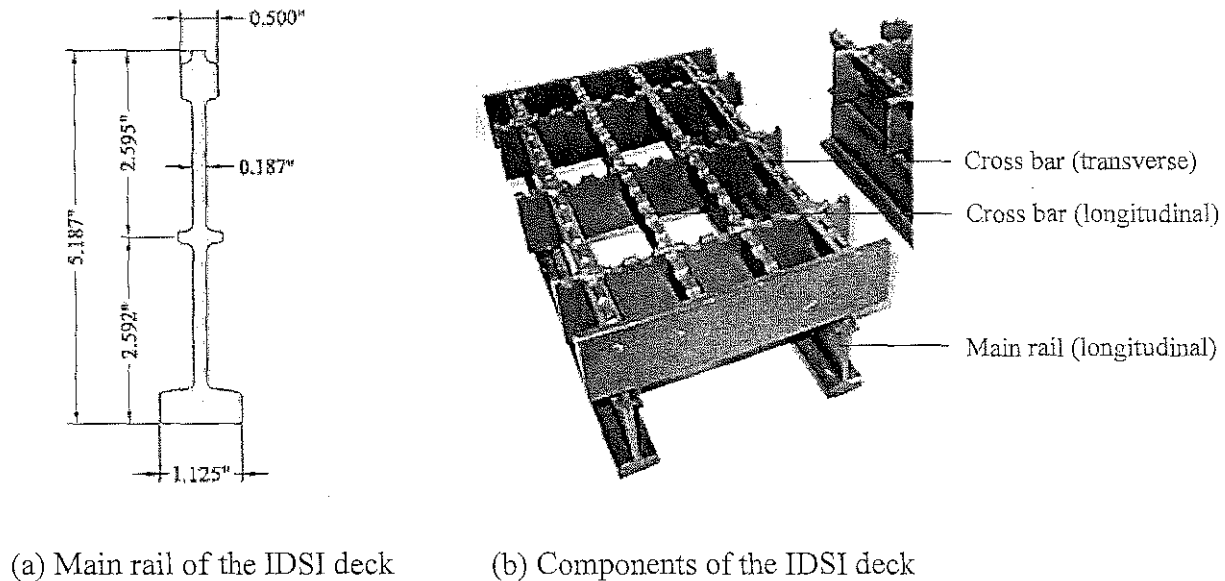


Fig. 2.1.1 – Steel grid decking manufactured by Interlocking Deck Systems International (IDSI), Inc (2004).

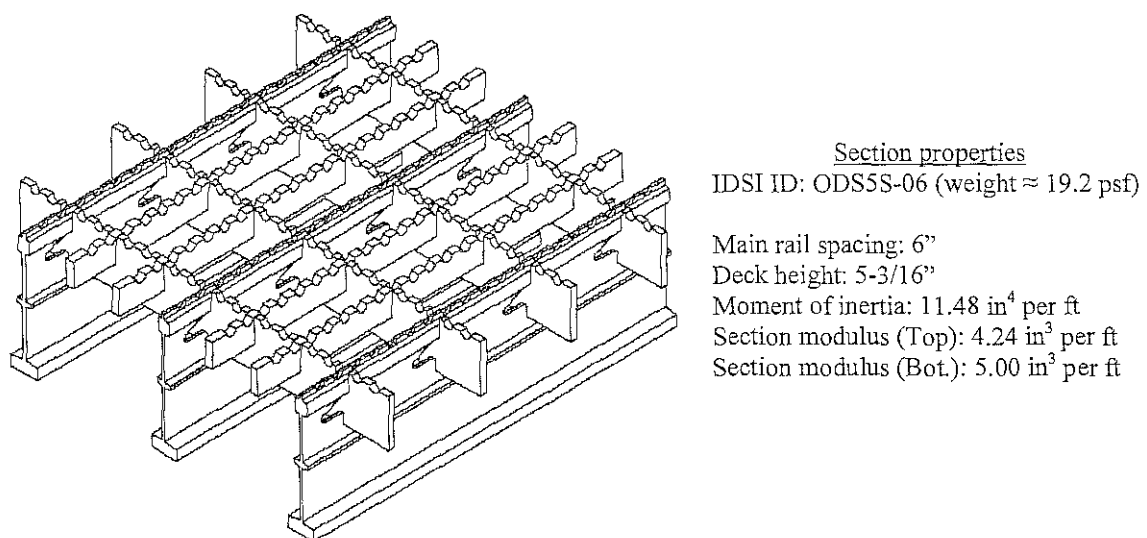


Fig. 2.1.2 – Section properties of the IDSI's deck with 6-in main rail spacing (2004).

The IDSI's decks are designed in accordance with AASHTO Allowable Stress Design (2002). The load capacities of steel decks with 6-in main rail spacing are tabulated in Table 2.1.1 (IDSI 2004). As illustrated, two different steel grades of yield strengths 36 ksi and 50 ksi, respectively, are considered for design trucks of HS 20 (MS 18) and HS25 (MS 22) – 25% weight or load increase of the HS 20 truck type.

Table 2.1.1. Load table for IDSI steel decks (2004)

IDSI ID	HS 20 (MS 18) Max. Cont. Clear Span			HS 25 (MS 22) Max. Cont. Clear Span		
	Transverse/Parallel to Traffic		Deflection $L/800$	Transverse/Parallel to Traffic		Deflection $L/800$
	36 ksi	50 ksi		36 ksi	50 ksi	
ODS5S-06	5.34 ft	7.19 ft	5.61 ft	5.01 ft	6.74 ft	5.43 ft

- Apply only for ODS5S-06 where main rails are 6-in center-to-center
- Modulus of elasticity of steel decks = 29×10^6 psi
- Clear span = L
- Deflection limits shown are independent of the main rail orientation for AASHTO ASD method
- Steel strength limits = 27 ksi for 50 ksi yield steel or 20 ksi for 36 ksi yield steel
- Fatigue was not considered

2.2 STEEL CHANNELS (C)

The steel channel (C) used in the John A. Roebling Bridge is a C10x20, as shown in Fig. 2.2.1.

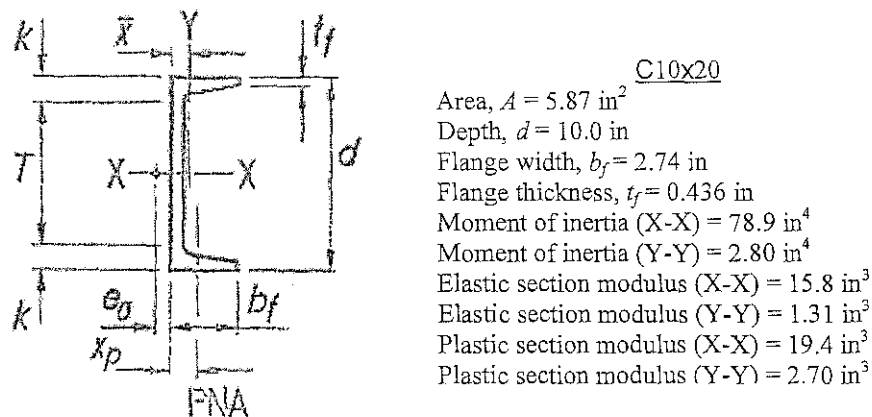


Fig. 2.2.1 – Properties of a C10x20 channel section.

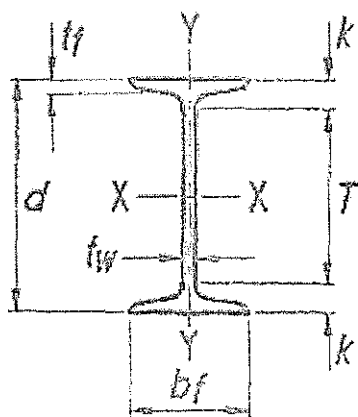
The allowable flexural and shear capacities presented in Table 2.2.1 for the C10x20 were determined per the 2005AISC Allowable Stress Design (ASD).

Table 2.2.1. Flexural and shear capacity of the C10x20 channel section

Member	Steel Grade	Allowable M_a	Allowable V_a
C10x20	A36 (36 ksi)	31.3 k-ft	49.0 k

2.3 STEEL STANDARDS (S)

There are two types of steel standards (**S**) used in the John A. Roebling Bridge: S15x50 and S20x66. Only the capacities of the S15x50 (Fig. 2.3.1) were evaluated as it is the smaller and the more critical structural member in this case.



S15x50

Area, $A = 14.7 \text{ in}^2$
 Depth, $d = 15.0 \text{ in}$
 Flange width, $b_f = 5.64 \text{ in}$
 Flange thickness, $t_f = 0.622 \text{ in}$
 Web thickness, $t_w = 0.550 \text{ in}$
 Moment of inertia (X-X) = 485 in^4
 Moment of inertia (Y-Y) = 15.6 in^4
 Elastic section modulus (X-X) = 64.7 in^3
 Elastic section modulus (Y-Y) = 5.53 in^3
 Plastic section modulus (X-X) = 77.0 in^3
 Plastic section modulus (Y-Y) = 9.99 in^3

Fig. 2.3.1 – Properties of a S15x50 standard section.

The allowable flexural and shear capacities presented in Table 2.3.1 for the standard section S15x50 were determined per the 2005AISC Allowable Stress Design (ASD).

Table 2.3.1. Flexural and shear capacity of the S15x50 standard section

Member	Steel Grade	Allowable M_a	Allowable V_a
S15x50	A7 (33 ksi)	95.0 k-ft	109.0 k

2.4 STEEL BUILT-UP MEMBER

The built-up members supporting the open grid steel decking, channels, and standards, have a 36-in height and are composed of four angles L6x4x1/2 (two at top and two at bottom), four angles L3x3x5/16 (two at top and two at bottom), and a steel plate 36x3/8 (Fig. 2.4.1). Intermediate web stiffeners are not shown in Fig. 2.4.1.

The allowable flexural and shear capacities presented in Table 2.4.1 for the built-up members were determined per the 2005 AISC Allowable Stress Design (ASD).

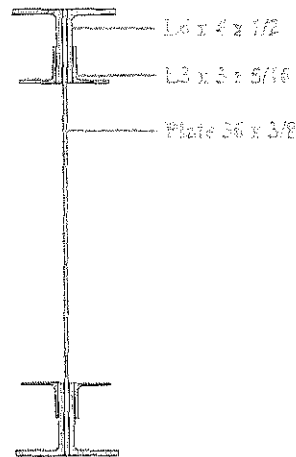


Fig. 2.4.1 – 36-inch built-up section.

Table 2.4.1. Flexural and shear capacity of 36-inch built-up section.

Member	Steel Grade	Allowable M_a	Allowable V_a
36-inch built-up	A36 (36 ksi)	549.7 k-ft	175.0 k

3 BRIDGE LOADING

Two types of gravity loads are considered in the analysis: self-weight loads of the structural and non-structural elements, and live loads.

3.1 SELF-WEIGHT LOADS

Attributable self-weight loads include loads of the bridge deck structural elements (i.e., steel decking, channel sections, standard sections, and built-up sections) and non-structural elements (i.e., electrical and mechanical conduits, traffic signs, posts, etc.).

3.2 LIVE LOADS

By definition, live loads are transient loads. In this study, live loads are contributed by the different truck and bus types.

3.2.1 *Truck Types*

The four truck types traversing the bridge are presented in Table 3.1.

3.2.2 *Bus Types*

The four bus types traversing the bridge are presented in Table 3.2.

3.3 ASSUMPTIONS

The following assumptions are introduced in the analysis:

- A 30% impact load is considered in the analysis. This is in accordance with the 2002 AASHTO Standard Specification Section 3.8.2.
- Two vehicles (i.e., trucks and/or buses) can travel parallel to each other on the bridge at the same time to produce the maximum load effect. This condition applies to certain structural elements (i.e., channel sections and the 36-in built-up member).

Table 3.1. Trucks Traversing the Roebling Bridge

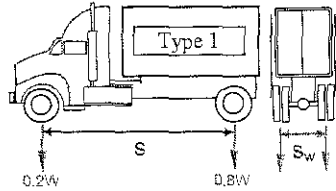
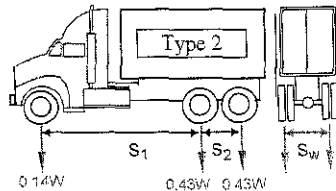
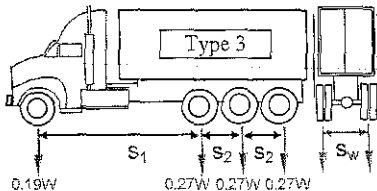
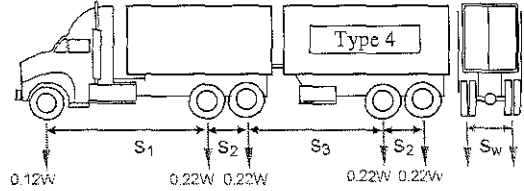
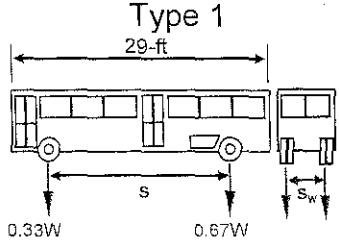
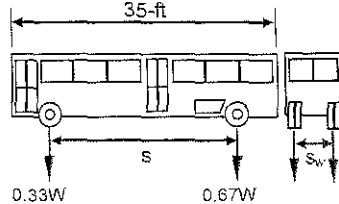
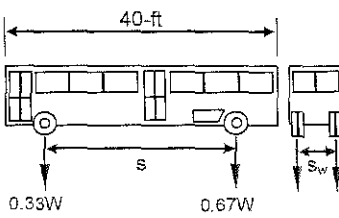
Truck Type	Truck Information	
	Axle Spacing s	Wheel Spacing s_w
	$s = 14'-0"$	6'-0"
	$s_1 = 12'-0"$ $s_2 = 4'-0"$	6'-0"
	$s_1 = 12'-0"$ $s_2 = 4'-0"$	6'-0"
	$s_1 = 12'-0"$ $s_2 = 4'-0"$ $s_3 = 14'-0"$	6'-0"

Table 3.2. Buses Traversing the Roebling Bridge

Bus Type	Bus Information		
	Gross Vehicle Weight* W	Axle Spacing** s	Wheel Spacing** s_w
<p>Type 1</p> 	30,000 lbs (15.00 Tons)	13' 6"	8' 1" (+/- 1")
<p>Type 2</p> 	39,500 lbs (19.75 Tons)	18' 4"	8' 3" (+/- 1")
<p>Type 3</p> 	39,500 lbs (19.75 Tons)	23' 8"	8' 3" (+/- 1")

* The Gross vehicle weight is the weight for the fully loaded bus. The information was provided by the Transit Authority of Northern Kentucky (TANK).

** Information provided by the Transit Authority of Northern Kentucky (TANK).

4 ELEMENT SECTIONAL LOSSES AND STRENGTH CAPACITY LOSSES

Recent field inspections revealed that some structural elements in the deck have experienced sectional loss up to 20%. The loss can be attributed to rust, visible cracks, etc. An accurate estimate of the section loss requires element removal from the bridge, cleaning, detailed measurements, etc. Consequently, an estimate based on visual inspection and field measurements is more practical. However, only visible losses can be measured, and these generally underestimate the actual section losses (e.g., cracks that are not visible to the naked eye, etc.).

The sectional losses reduce the sectional geometric properties of the element (area A , moment of inertia I , section modulus S , etc.) and, in turn, reduce the strength capacity of the section in bending, shear, etc.

In order to quantify the relation between the percentage of section loss and the percentage of capacity loss, results are presented in tables in chapters 5, 6, 7, and 8 for 10% to 40% loss in section, in 10% increments. The percentage loss is applied uniformly to the flanges and webs of the steel sections (e.g., C and S sections) and to the walls of the steel sections that make up the built-up member. For example, a 10% section loss is applied by reducing the thickness of the flanges and webs by 10%.

Table 4.1 shows that, a 10% section loss leads to a 19% loss in allowable bending moment capacity and 10% loss in allowable shear capacity of the built-up section. A 20% section loss leads to 38% loss in allowable bending moment capacity and 20% in allowable shear capacity of the built-up section.

Table 4.1. Effect of 10%, 20%, 30%, 40%, and 50% sectional loss on the sectional properties and capacities of the 36" built-up member.

Section Properties and allowable Shear and Bending Capacities	Value of the section properties and capacities for different % in sectional loss								
	0% sectional loss	10% sectional loss		20% sectional loss		30% sectional loss		40% sectional loss	
		Value	% reduction = η	Value	% reduction = η	Value	% reduction = η	Value	% reduction = η
Area, A (in ²)	39.62	32.90	17%	26.79	32%	22.18	44%	17.41	56%
Moment of inertia, I_x (in ⁴)	7,580	5,923	22%	4,750	37%	3,686	51%	2,702	64%
Elastic section modulus, S_x (in ³)	421	340	19%	260	38%	204	52%	150	64%
Plastic section modulus, Z_x (in ³)	523	422	19%	322	38%	251	52%	188	64%
Shear capacity, V_a (k)	175	157	10%	139	20%	121	31%	104	41%
Bending moment capacity, M_a (k-ft)	549.7	445	19%	341	38%	264	52%	198	64%

Notes for Table 4.1:

- 1- The sectional loss in the bridge elements may occur as a result of a crack propagating in the web or the flange(s). In this case, the section properties and capacities listed in column 1 in table 4.1 can be derived based on the uncracked section in order to determine % reduction.
- 2- In case a % sectional loss falls between two values in Table 4.1 (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

5 ELEMENT LEVEL ANALYSIS

5.1 STRUCTURAL IDEALIZATION

5.1.1 STEEL DECKING

The following assumptions are applied to the open steel grid decking for this level of analysis:

- The deck is to be continuously supported over several spans; and
- The channels (**C**), supporting the deck, are idealized as simple supports (Fig. 5.1.1).

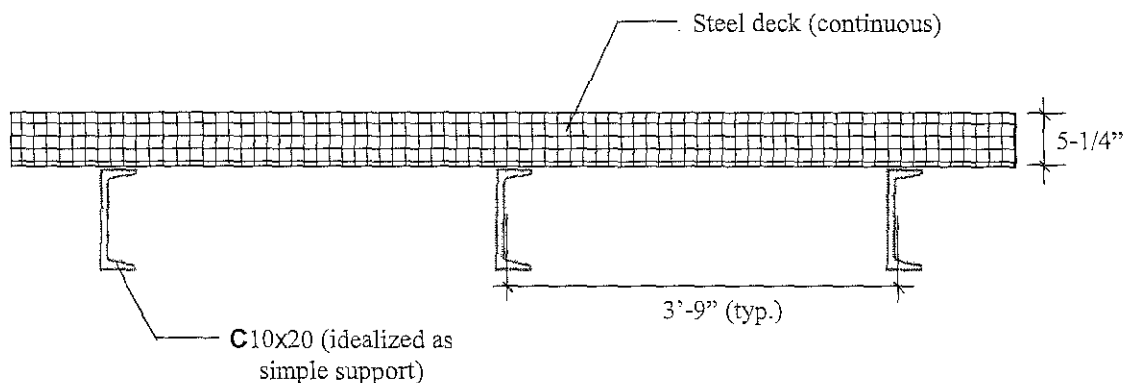


Fig. 5.1.1 – Idealization of steel decking for the Element Level Analysis.

5.1.2 STEEL CHANNEL SECTION

The following assumptions are applied to the steel channel for this level of analysis:

- Each channel (**C**) is continuously supported over several spans (i.e., constant spacing of 5'-3") with the supporting standard (**S**) sections idealized as simple supports (Fig. 5.1.2); and
- The tributary area is bounded by the center to center spacing of the **C**-sections and **S**-section (3'-9" and 5'-3", respectively).

5.1.3 STEEL STANDARD SECTION

The following assumptions are applied to the steel channel for this level of analysis:

- Each standard (**S**) section is idealized as a single-span beam with the supporting 36-in deep built-up members idealized as simple or fixed support depending on the type of connection to the built-up member. The simple connection is the critical one. (Fig. 5.1.3); and
- The tributary area is bounded by the center to center spacing of the **S**-sections and the built-up member (5'-3" and 15'-0", respectively).

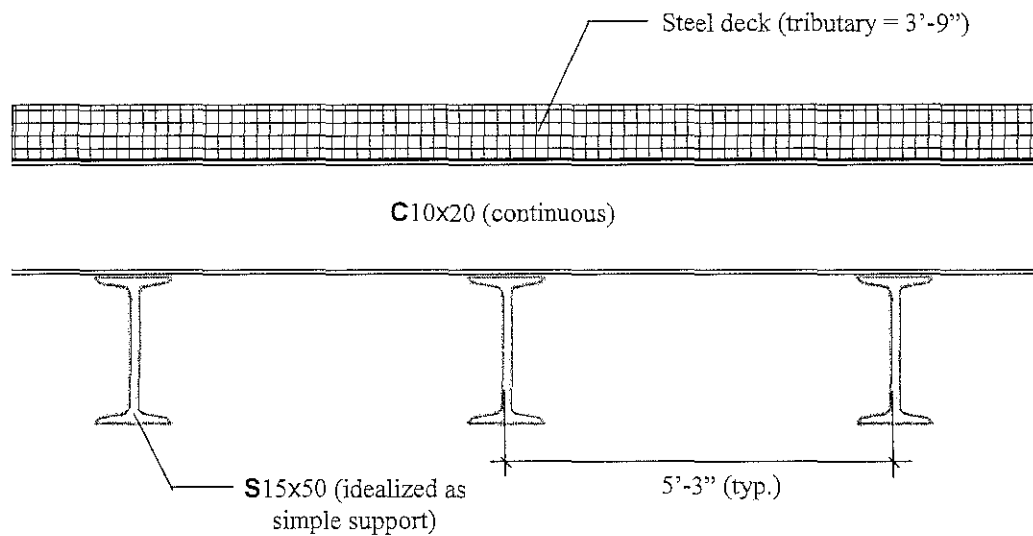


Fig. 5.1.2 – Idealization of steel channel (C) section for the Element Level Analysis.

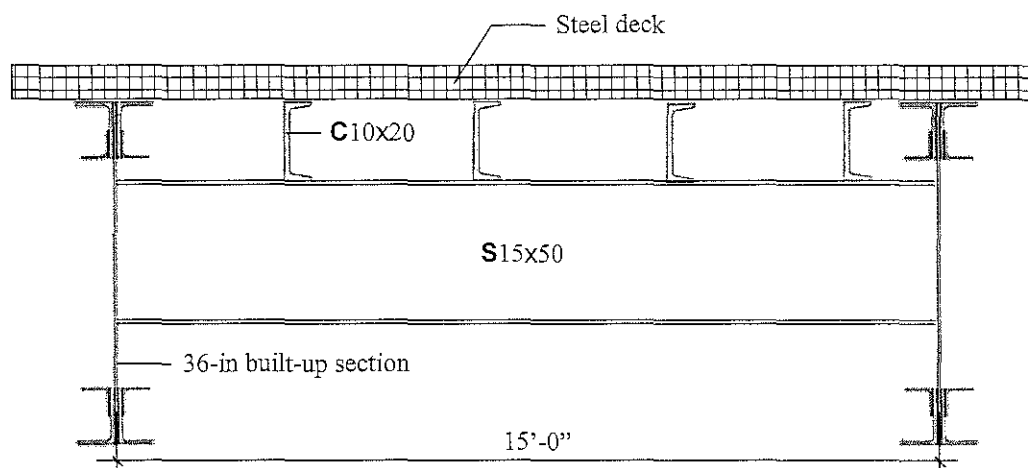


Fig. 5.1.3 – Idealization of steel standard (S) section for the Element Level Analysis.

5.1.4 BUILT-UP SECTION

The 36-in deep built-up section is represented by a beam with supporting cables idealized as simple supports (Fig. 5.1.4). The tributary area of the vehicle traffic portion of the deck is bounded by the width of the bridge deck supported by the suspender cable and the center to center spacing of the built-up member (32'-0" and 15'-0", respectively). The tributary area of each overhang segment (or pedestrian portion) is bounded by the length of the overhang and the center to center spacing of built-up member (8'-6" and 15'-0", respectively).

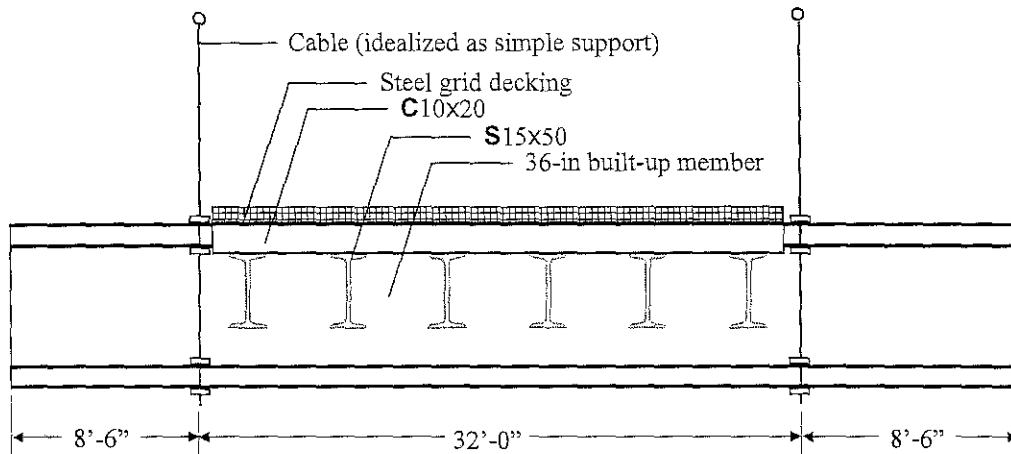


Fig. 5.1.4 – Idealization of 36-in deep built-up member.

5.2 MAXIMUM ALLOWABLE GROSS VEHICLE WEIGHT (GVW)

5.2.1 Maximum Allowable GVW on the Steel Decking

The commercially available open steel grid decking manufactured by the Interlocking Deck Systems International (IDSI), Inc. (2004), is comparable to the existing steel decking and is used in this case to determine the load capacity. The steel decking can carry a HS25 and HS20 truck at spacing of 5.01 ft and 5.34 ft, respectively. The existing steel decking is supported by Channel sections at spacing of 3.75 ft. It is therefore concluded that the steel decking will be able, at 0% loss in bending capacity, to carry any vehicle types shown in Tables 3.1 and 3.2, and will not control the determination of the allowable gross vehicle weight.

5.2.2 Maximum Allowable GVW on the Steel Channel Sections

C10x20 sections are used to support the open grid steel decking. The A36 channel section has an allowable bending capacity of 31.3 k-ft and an allowable shearing capacity of 49 kips. Shear capacity, deflection limit, and connection capacity do not control and will not be

included in the sample calculations. The maximum allowable GVWs at 0% loss in bending capacity (or $\eta = 0$) are: 34.38 tons, 31.98 tons, 33.96 tons, 43.26 tons, and 36.40 tons, for the 2-, 3-, 4-, and 5-axle trucks, and the 2-axle buses, respectively. Shear and deflection do not control.

5.2.3 Maximum Allowable GVW on the Steel Standard Sections

S15x50 and S20x66 sections are used to support the steel channels. The A36 S15x50 standard section is the critical section. It has an allowable bending capacity of 95 k-ft and an allowable shearing capacity of 109 kips. Shear capacity, deflection limit, and connection capacity do not control and will not be included in the sample calculations. The maximum allowable GVWs at 0% loss in bending capacity (or $\eta = 0$) are: 42.50 tons, 39.53 tons, 41.98 tons, 53.49 tons, and 45.00 tons, for the 2-, 3-, 4-, and 5-axle trucks, and the 2-axle buses, respectively.

5.2.4 Maximum Allowable GVW on the Steel Built-up Sections

Each A36 built-up member has an allowable bending capacity of 549.7 k-ft and an allowable shear capacity of 175 kips. Shear capacity, deflection limit, and connection capacity do not control and will not be included in the sample calculations. The maximum allowable GVWs at 0% loss in bending capacity (or $\eta = 0$) are: 20.17 tons, 21.52 tons, 24.09 tons, 36.68 tons, and 26.50 tons, for 2-, 3-, 4-, and 5-axle trucks, and the 2-axle buses, respectively.

5.3 CRITICAL MEMBER FOR DETERMINING THE GVW

The results from the Element Level Analysis indicate that the built-up member is the critical member for determining the load carrying capacity. In the following section, the results are generated for the built-up member.

5.4 SAMPLE CALCULATIONS FOR THE GROSS VEHICLE WEIGHT (GVW) LIMIT

The following illustrates how the maximum allowable GVW is determined for the critical member (i.e., built-up section):

5.4.1. Tributary Width, Length, and Area

Tributary width of the built-up member excluding the overhang = 15 ft

Tributary length of the built-up member excluding the overhang = 32 ft

Tributary area of the built-up member excluding the overhang = (15×32) ft²

Tributary width of the built-up member overhang = 15 ft

Tributary length of the built-up member overhang = 8.5 ft

Tributary area of the built-up member overhang = (15×8.5) ft²

5.4.2. Dead Loads

Open grid steel deck weight = 20 psf

Weight of other structural and non-structural components excluding overhang = 40 psf

Total dead weight excluding = $w_d = (20 + 40) = 60 \text{ psf} = 0.06 \text{ ksf}$

Dead weight on the overhang = $w_{oh} \simeq 50 \text{ psf} = 0.05 \text{ ksf}$

5.4.3. Live Loads

Live load = Vehicle loading = Two trucks or buses placed side-by-side, separated by a distance of 4 ft (see Figs. 5.4.1).

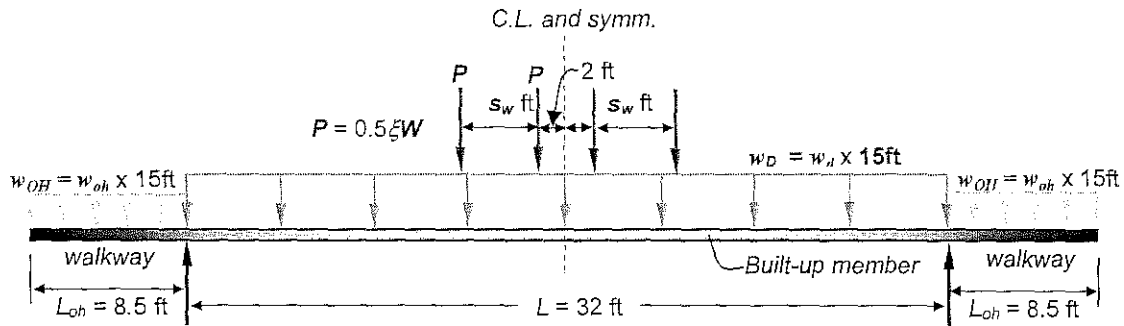


Fig. 5.4.1 – Loadings on 36-in built-up section.

5.4.3.1. Live Load Distribution for the Front Axle

For the front axle, the load P in Fig. 5.4.1 represents the resultant pressure under the tire at one end of the front axle. Consequently, P is equal to 50% of the weight attributed to the front axle, and can be represented by:

$$P = 0.5\xi W$$

where ξ = fraction of gross vehicle weight (GVW) attributed to the axle (Tables 3.1 and 3.2), and W = gross vehicle weight.

5.4.3.2. Live Load Distribution for the Rear Single and Tandem Axles

For the rear single axle, ξ = fraction of gross vehicle weight (GVW) attributed to the single rear axle (Truck Type 1 or Bus Type 1, 2, and 3 in Tables 3.1 and 3.2, respectively).



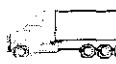


For the rear tandem axle(s) for Truck Type 2 and 4 in Table 3.1, the centerline of the tandem axles is placed over the built-up member. The percentage of the load distribution to the member is derived by considering a beam (S - section) in the longitudinal direction spanning between three built-up members with the centerline of the dual tandem axles placed on the built-up member in the middle. The built-up members are assumed to provide a simple support for the longitudinal beam.

For the three rear axles for Truck Type 3 in Table 3.1, the centerline of the middle rear axle is placed over the built-up member. The percentage of the load distribution to the member is derived by considering a beam (S - section) in the longitudinal direction

spanning between three built-up members with the middle axle placed on the built-up member in the middle. The built-up members are assumed to provide a simple support for the longitudinal beam.

Table 5.4.1 presents the values of the fraction of GVW, ξ , attributed to the rear axle(s) for the trucks and buses in Tables 3.1 and 3.2, respectively.

Table 5.4.1 – Fraction of gross vehicle weight, ξ , attributed to the rear axle(s)

Fraction of gross vehicle weight attributed to the rear axle(s)	Vehicle Type				
	Type – 1 	Type – 2 	Type – 3 	Type – 4 	Types 1, 2 & 3 
ξ	0.8	0.75	0.67	0.44	0.67

For the rear axle(s), the load P can also be represented by:

$$P = 0.5\xi W$$

where ξ = fraction of gross vehicle weight (GVW) attributed to the rear axle(s) in Table 5.4.1, and W = gross vehicle weight.

5.4.4. Bending Moments

Moment due to dead load, M_D , (Fig. 5.4.2):

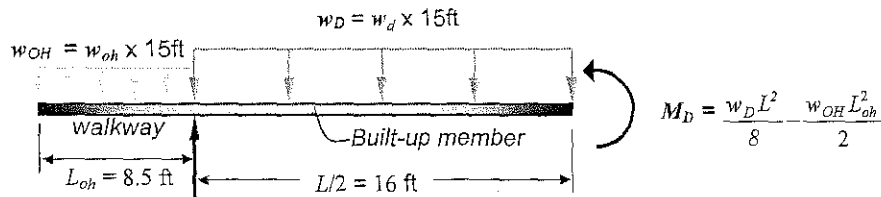


Fig. 5.4.2 – Moment due to dead loads.

Moment due to vehicle live load including a 30% impact load, M_{L+I} , (Fig. 5.4.3):

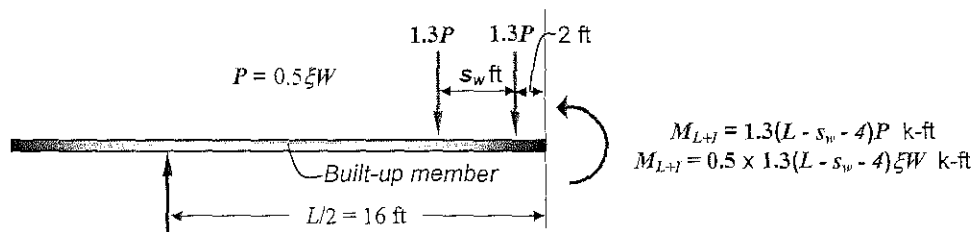


Fig. 5.4.3 – Moment due to truck or bus loads.

5.4.5. Allowable GVW Calculation

Based on the allowable stress design (ASD), $M_a \geq M_D + M_{L+I}$ or $M_{L+I} \leq M_a - M_D$. When considering a loss in the allowable bending capacity (M_a) of magnitude η (where $\eta = 19\%, 38\%$, etc., Table 4.1), the moment relationship can be written as follows:

$$M_{L+I} \leq (1 - \eta) M_a - M_D \quad (\text{Eq. 5.1})$$

$$0.5 \times 1.3(L - s_w - 4)\xi W \leq (1 - \eta)M_a - \frac{w_D L^2}{8} + \frac{w_{OH} L_{oh}^2}{2} \quad (\text{Eq. 5.2})$$

$$W = \frac{(1 - \eta) M_a - \frac{w_D L^2}{8} + \frac{w_{OH} L_{oh}^2}{2}}{0.5 \times 1.3(L - s_w - 4)\xi} \quad (\text{Eq. 5.3})$$

Considering that the built-up member has a 20% sectional loss [or loss in bending capacity of 38% (or $\eta = 0.38$) in Table 4.1] and is subjected to the 4-axle truck (Type 3 in Table 3.1), the maximum allowable gross vehicle weight (W) can be determined as follows:

$$M_a = 549.7 \text{ k-ft (Table 4.1 for 0\% sectional loss)}$$

$$\eta = 0.38 \text{ (38\% loss in bending capacity)}$$

$$w_D = 0.9 \text{ k/ft}$$

$$w_{OH} = 0.75 \text{ k/ft}$$

$$L = 32 \text{ ft}$$

$$L_{oh} = 8.5 \text{ ft}$$

$$s_w = 6 \text{ ft (Truck Type 3 in Table 3.1)}$$

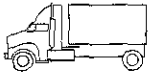



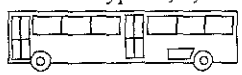
$$\xi = 0.67 \text{ (Truck Type 3 in Table 5.4.1)}$$

$$W = 26.38 \text{ k} = 13.19 \text{ tons}$$

5.5 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR TRUCKS AND BUSES

The allowable gross vehicle weights (GVWs) for the 2-, 3-, 4-, and 5-axle trucks, and the Type 1, 2, and 3 two-axle buses, are presented in Table 5.5.1 for different percentages of sectional losses varying from 10% to 40%, in 10% increments.

Table 5.5.1. Element Level Analysis - Allowable Gross Vehicle Weight (GVW) in Tons for Different Percentages of Sectional Losses in the Built-Up Member

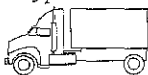
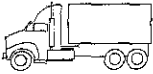
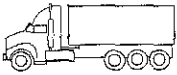

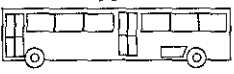
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	20.17 tons	15.61 tons	11.04 tons	7.68 tons	4.80 tons
3-axle truck – Type 2 	21.52 tons	16.65 tons	11.78 tons	8.19 tons	5.12 tons
4-axle truck – Type 3 	24.09 tons	18.64 tons	13.19 tons	9.17 tons	5.73 tons
5-axle truck – Type 4 	36.68 tons	28.38 tons	20.08 tons	13.97 tons	8.72 tons
2-axle bus - Types 1, 2, & 3 	26.50 tons	20.50 tons	14.51 tons	10.09 tons	6.30 tons

* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

5.6 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR DIFFERENT DECK WEIGHTS


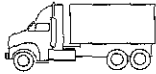
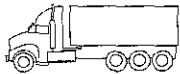


In the event that replacement of the open grid deck will take place in the future, results are presented in Tables 5.6.1 to 5.6.5 for different deck weights (10 psf to 50 psf in 10 psf increments). The current deck weight is 20 psf.

Table 5.6.1. Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf.

Deck Weight = 10 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	21.01 tons	16.45 tons	11.88 tons	8.52 tons	5.64 tons
3-axle truck – Type 2 	22.41 tons	17.55 tons	12.68 tons	9.09 tons	6.01 tons
4-axle truck – Type 3 	25.09 tons	19.64 tons	14.19 tons	10.17 tons	6.73 tons
5-axle truck – Type 4 	38.21 tons	29.91 tons	21.61 tons	15.49 tons	10.25 tons
2-axle bus - Types 1, 2, & 3 	27.60 tons	21.60 tons	15.61 tons	11.19 tons	7.40 tons

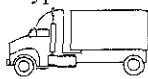
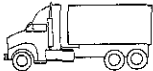
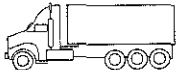


* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

Table 5.6.2. Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf.

Deck Weight = 20 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	20.17 tons	15.61 tons	11.04 tons	7.68 tons	4.80 tons
3-axle truck – Type 2 	21.52 tons	16.65 tons	11.78 tons	8.19 tons	5.12 tons
4-axle truck – Type 3 	24.09 tons	18.64 tons	13.19 tons	9.17 tons	5.73 tons
5-axle truck – Type 4 	36.68 tons	28.38 tons	20.08 tons	13.97 tons	8.72 tons
2-axle bus - Types 1, 2, & 3 	26.50 tons	20.50 tons	14.51 tons	10.09 tons	6.30 tons


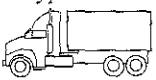
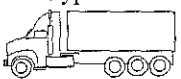


* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

Table 5.6.3. Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf.

Deck Weight = 30 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	19.34 tons	14.77 tons	10.21 tons	6.84 tons	3.96 tons
3-axle truck – Type 2 	20.62 tons	15.76 tons	10.89 tons	7.30 tons	4.22 tons
4-axle truck – Type 3 	23.09 tons	17.64 tons	12.19 tons	8.17 tons	4.73 tons
5-axle truck – Type 4 	35.16 tons	26.86 tons	18.56 tons	12.44 tons	7.20 tons
2-axle bus - Types 1, 2, & 3 	25.40 tons	19.40 tons	13.40 tons	8.99 tons	5.20 tons


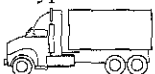



* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

Table 5.6.4. Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf.

Deck Weight = 40 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	18.50 tons	13.93 tons	9.37 tons	6.00 tons	3.12 tons
3-axle truck – Type 2 	19.73 tons	14.86 tons	9.99 tons	6.40 tons	3.33 tons
4-axle truck – Type 3 	22.09 tons	16.63 tons	11.18 tons	7.17 tons	3.73 tons
5-axle truck – Type 4 	33.63 tons	25.33 tons	17.03 tons	10.91 tons	5.67 tons
2-axle bus - Types 1, 2, & 3 	24.29 tons	18.30 tons	12.30 tons	7.88 tons	4.10 tons

* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

Table 5.6.5. Element Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf.

Deck Weight = 50 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	17.66 tons	13.09 tons	8.53 tons	5.16 tons	2.28 tons
3-axle truck – Type 2 	18.83 tons	13.97 tons	9.10 tons	5.51 tons	2.43 tons
4-axle truck – Type 3 	21.08 tons	15.63 tons	10.18 tons	6.17 tons	2.72 tons
5-axle truck – Type 4 	32.10 tons	23.80 tons	15.50 tons	9.39 tons	4.15 tons
2-axle bus - Types 1, 2, & 3 	23.19 tons	17.20 tons	11.20 tons	6.78 tons	3.00 tons

* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher than the one in question (e.g. 10% and 20% sectional loss) should yield adequate results.

6 SECTIONAL LEVEL ANALYSIS I

6.1 STRUCTURAL IDEALIZATION

At this level of analysis, a 3-D structural/computer model of a portion of the span is generated and analyzed (Fig. 6.1). The rule for generating a partial 3-D rendition of the superstructure is that the span (L_I) under consideration should be at least three (3) times the width (B) of the roadway.

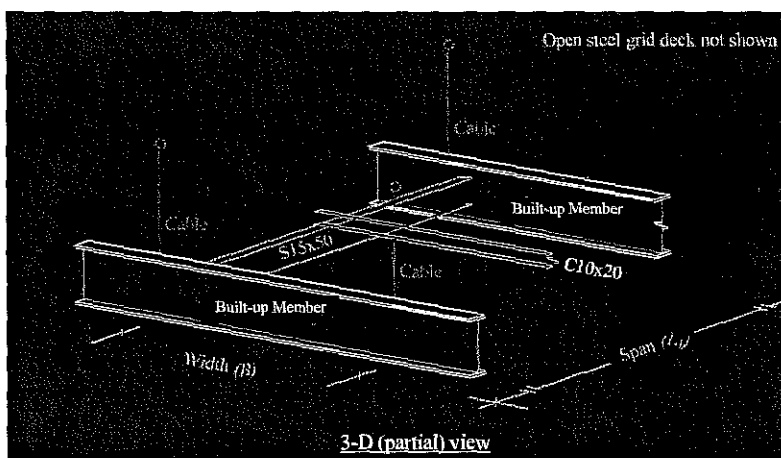


Fig. 6.1 – Structural idealization of Sectional Level Analysis I.

The width (B) of the bridge deck is approximately 32', excluding the two overhanging pedestrian walkways. To maintain a minimum span-to-width ratio of three (3), the span (L_I) length needs to be 96'. The center-to-center spacing of the 36-in built-up members is 15'-0". Therefore, in this case, seven (7) spans are needed to achieve the minimum span-to-width ratio (i.e., $L_I/B = 3.28$, in this case). As depicted in Fig. 6.2, the cable supports are idealized as simple supports at respective locations.

6.2 ASSUMPTIONS

The assumptions presented in Section 3.3 are similarly applied at this level of analysis. In addition, due to the presence of different structural elements (i.e., channels, standard sections, and built-up sections) in the model, the same percent sectional loss was applied to all members.

6.3 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR TRUCKS AND BUSES

The allowable gross vehicle weight (GVW) of each truck type and bus type is determined in the following manner:

1. Assume a total truck or bus weight.
2. For each truck or bus type, the weight is distributed in accordance with Table 3.1 for trucks or Table 3.2 for buses.
3. Perform and carry out the structural analysis on the model.
4. Compare the members' demands to the members' capacities (i.e., bending, shear, etc.). It should be noted that the different sectional losses presented in Table 4.1 were taken into consideration when deriving the allowable gross vehicle weights (GVWs).
5. Steps 1 through 4 are repeated until the members' demands reach the members' capacities and the truck or bus weight is recorded.
6. The maximum allowable truck or bus weight, W , is then derived by dividing the weight obtained in Step 5 by a factor of 1.3 to account for the 30% impact factor.

Similar to the element level analysis, the built-up members controls the maximum allowable GVW. The allowable GVWs for the 2-, 3-, 4-, and 5-axle trucks, and the Type 1, 2, and 3 two-axle buses, are presented in Table 6.1 for different percentages of sectional losses varying from 10% to 40%, in 10% increments.

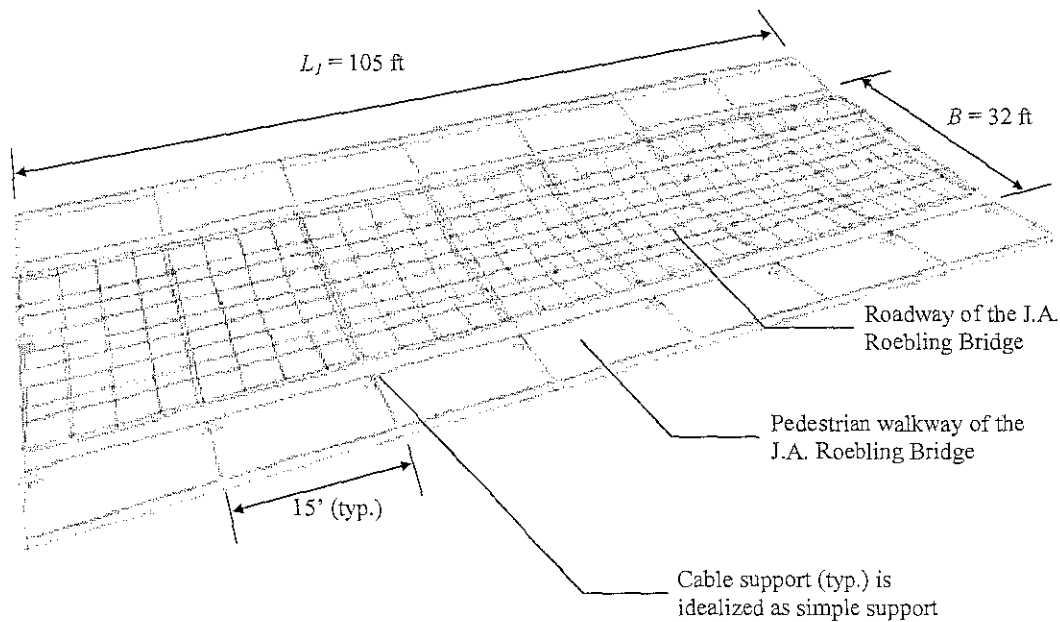

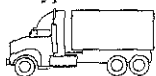
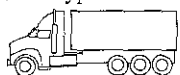

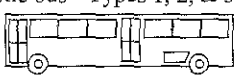


Fig. 6.2 – Structural model for Sectional Level Analysis I.

Table 6.1. Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member.

Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	40.18 tons	32.14 tons	24.91 tons	19.28 tons	14.46 tons
3-axle truck – Type 2 	46.39 tons	37.11 tons	28.76 tons	23.21 tons	16.70 tons
4-axle truck – Type 3 	59.91 tons	47.92 tons	37.14 tons	28.75 tons	21.56 tons
5-axle truck – Type 4 	86.95 tons	69.56 tons	53.90 tons	41.73 tons	31.30 tons
2-axle bus - Types 1, 2, & 3 	45.66 tons	36.52 tons	28.30 tons	21.91 tons	16.43 tons

6.4 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR DIFFERENT DECK WEIGHTS

In the event that replacement of the open grid deck will take place in the future, results are presented in Tables 6.4.1 to 6.4.5 for different deck weights (10 psf to 50 psf, in 10 psf increments). The current deck weight is 20 psf.

Table 6.4.1. Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf.


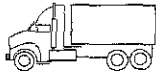
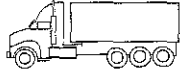
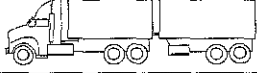
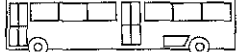
Deck Weight = 10 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	42.30 tons	33.84 tons	26.22 tons	20.30 tons	15.23 tons
3-axle truck – Type 2 	48.84 tons	39.07 tons	30.28 tons	23.44 tons	17.58 tons
4-axle truck – Type 3 	63.07 tons	50.45 tons	39.10 tons	30.27 tons	22.70 tons
5-axle truck – Type 4 	91.53 tons	73.22 tons	56.74 tons	43.93 tons	32.95 tons
2-axle bus - Types 1, 2, & 3 	48.07 tons	38.45 tons	29.80 tons	23.07 tons	17.31 tons

Table 6.4.2. Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf.

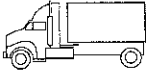
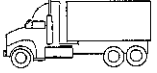
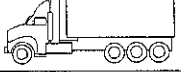
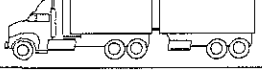

Deck Weight = 20 psf (same as Table 6.1)					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	40.18 tons	32.14 tons	24.91 tons	19.28 tons	14.46 tons
3-axle truck – Type 2 	46.39 tons	37.11 tons	28.76 tons	23.21 tons	16.70 tons
4-axle truck – Type 3 	59.91 tons	47.92 tons	37.14 tons	28.75 tons	21.56 tons
5-axle truck – Type 4 	86.95 tons	69.56 tons	53.90 tons	41.73 tons	31.30 tons
2-axle bus - Types 1, 2, & 3 	45.66 tons	36.52 tons	28.30 tons	21.91 tons	16.43 tons

Table 6.4.3. Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf.



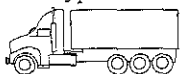

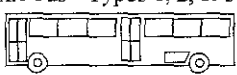
Deck Weight = 30 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	38.17 tons	30.53 tons	23.66 tons	18.32 tons	13.74 tons
3-axle truck – Type 2 	44.07 tons	35.25 tons	21.85 tons	16.92 tons	17.58 tons
4-axle truck – Type 3 	56.92 tons	45.53 tons	35.29 tons	27.32 tons	20.49 tons
5-axle truck – Type 4 	82.60 tons	66.08 tons	51.21 tons	39.64 tons	29.73 tons
2-axle bus - Types 1, 2, & 3 	43.38 tons	34.70 tons	26.89 tons	20.82 tons	15.61 tons

Table 6.4.4. Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf.

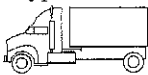
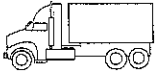
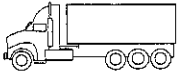
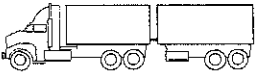
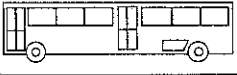

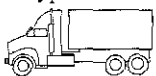
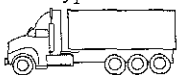

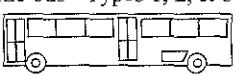
Deck Weight = 40 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	36.27 tons	29.01 tons	22.48 tons	17.40 tons	13.05 tons
3-axle truck – Type 2 	41.87 tons	33.49 tons	25.95 tons	20.09 tons	15.07 tons
4-axle truck – Type 3 	54.07 tons	43.25 tons	33.52 tons	25.95 tons	19.46 tons
5-axle truck – Type 4 	78.47 tons	62.77 tons	48.65 tons	37.66 tons	28.24 tons
2-axle bus - Types 1, 2, & 3 	41.21 tons	32.96 tons	25.55 tons	19.78 tons	14.83 tons

Table 6.4.5. Sectional Level Analysis I - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf.

Deck Weight = 50 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	34.45 tons	27.56 tons	21.35 tons	16.53 tons	12.40 tons
3-axle truck – Type 2 	39.78 tons	31.82 tons	24.66 tons	19.09 tons	14.32 tons
4-axle truck – Type 3 	51.37 tons	41.09 tons	31.84 tons	24.65 tons	18.49 tons
5-axle truck – Type 4 	74.55 tons	59.64 tons	46.22 tons	35.78 tons	26.83 tons
2-axle bus - Types 1, 2, & 3 	39.15 tons	31.32 tons	24.27 tons	18.79 tons	14.09 tons

7 SECTIONAL LEVEL ANALYSIS II

7.1 STRUCTURAL IDEALIZATION

At this level of analysis, 3-D structural/computer models of the main span and the approach spans are generated and analyzed separately. Fig. 7.1 shows a structural/computer model of the main span, and Fig. 7.2 shows a structural/computer model of one of the approach spans.

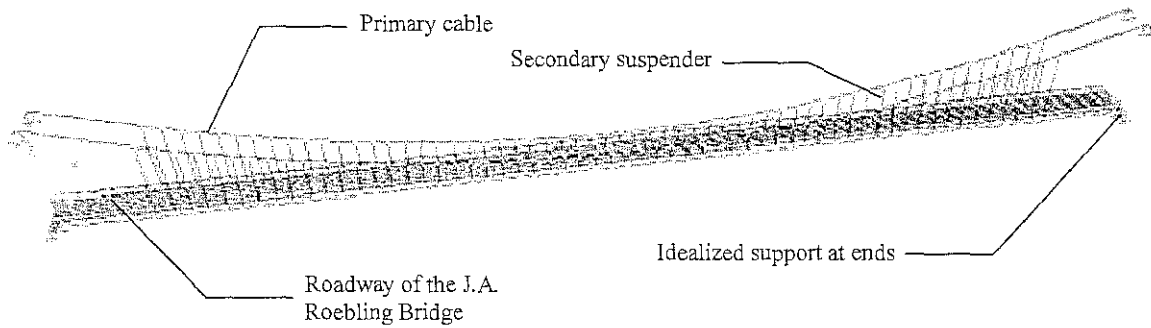


Fig. 7.1 – Structural model of the main span for Sectional Level Analysis II.

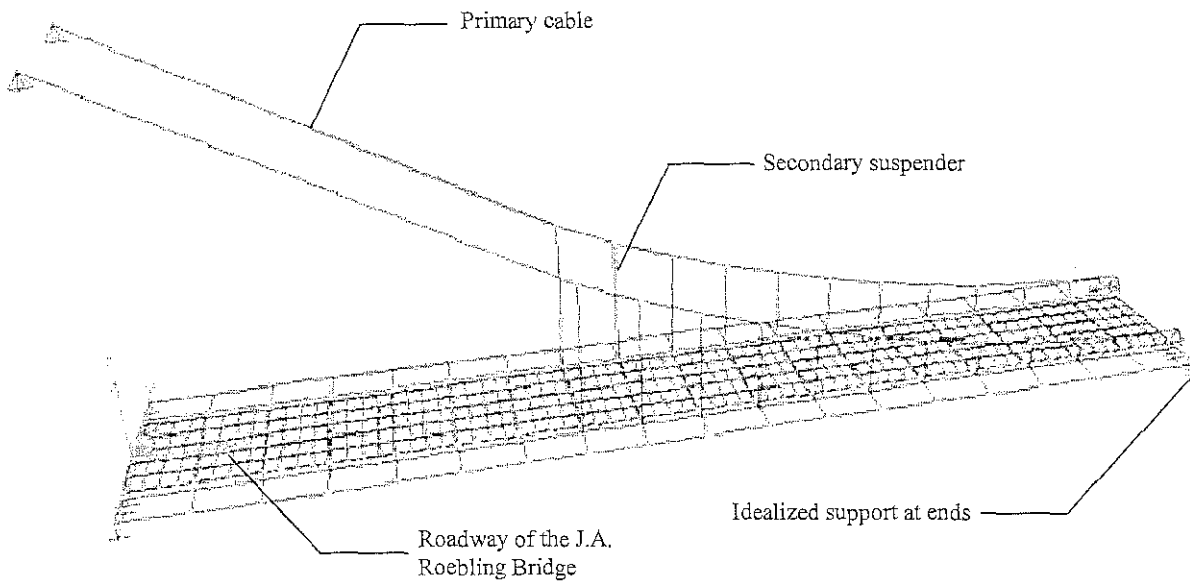


Fig. 7.2 – Structural model of the approach span for Sectional Level Analysis II.

7.2 ASSUMPTIONS


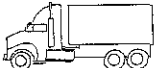



The assumptions presented in Section 3.3 are similarly applied at this level of analysis. In addition, due to the presence of different structural elements (i.e., channels, standard sections, and built-up sections) in the model, the same percent sectional loss was applied to all members.

7.3 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR TRUCKS AND BUSES

The determination of the allowable gross vehicle weight (GVW) of each truck type and bus type is determined in the manner described in section 6.3.

Similar to the element level analysis, the built-up members controls the maximum allowable GVW. The allowable GVWs for the 2-, 3-, 4-, and 5-axle trucks, and the Type 1, 2, and 3 two-axle buses, are presented in Table 7.1 for different percentages of sectional losses varying from 10% to 40%, in 10% increments.

Table 7.1. Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member.

Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	39.45 tons	31.56 tons	23.67 tons	17.75 tons	13.80 tons
3-axle truck – Type 2 	58.45 tons	46.76 tons	35.07 tons	26.30 tons	20.45 tons
4-axle truck – Type 3 	66.67 tons	53.33 tons	40.00 tons	30.00 tons	23.33 tons
5-axle truck – Type 4 	91.30 tons	73.04 tons	54.78 tons	41.08 tons	31.95 tons
2-axle bus - Types 1, 2, & 3 	44.57 tons	35.65 tons	26.74 tons	20.05 tons	15.59 tons

7.4 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR DIFFERENT DECK WEIGHTS

The allowable gross vehicle weights (GVWs) for the 2-, 3-, 4-, and 5-axle trucks, and the Type 1, 2, and 3 two-axle buses, are presented in Tables 7.4.1 – 7.4.5 for different percentages of sectional losses varying from 10% to 40%, in 10% increments; in addition to the different deck weights (10 psf to 50 psf in 10 psf increments). The current deck weight is 20 psf.

Table 7.4.1 Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf.


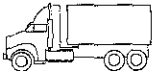
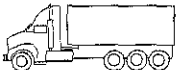

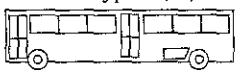
Deck Weight = 10 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	41.53 tons	24.91 tons	24.91 tons	18.68 tons	14.53 tons
3-axle truck – Type 2 	61.53 tons	49.22 tons	36.91 tons	27.68 tons	21.53 tons
4-axle truck – Type 3 	70.18 tons	56.14 tons	42.10 tons	31.58 tons	24.56 tons
5-axle truck – Type 4 	96.11 tons	76.88 tons	57.66 tons	43.24 tons	33.63 tons
2-axle bus - Types 1, 2, & 3 	46.92 tons	37.53 tons	28.15 tons	21.11 tons	16.42 tons

Table 7.4.2. Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf.

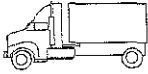
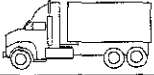
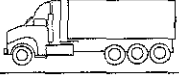


Deck Weight = 20 psf (same as Table 7.1)					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	39.45 tons	31.56 tons	23.67 tons	17.75 tons	13.80 tons
3-axle truck – Type 2 	58.45 tons	46.76 tons	35.07 tons	26.30 tons	20.45 tons
4-axle truck – Type 3 	66.67 tons	53.33 tons	40.00 tons	30.00 tons	23.33 tons
5-axle truck – Type 4 	91.30 tons	73.04 tons	54.78 tons	41.08 tons	31.95 tons
2-axle bus - Types 1, 2, & 3 	44.57 tons	35.65 tons	26.74 tons	20.05 tons	15.59 tons

Table 7.4.3. Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf.


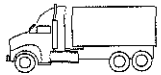
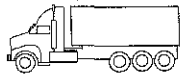


Deck Weight = 30 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	37.47 tons	29.97 tons	22.48 tons	16.86 tons	13.11 tons
3-axle truck – Type 2 	55.53 tons	44.42 tons	33.31 tons	24.98 tons	19.43 tons
4-axle truck – Type 3 	63.33 tons	50.66 tons	37.99 tons	28.49 tons	22.16 tons
5-axle truck – Type 4 	86.73 tons	69.38 tons	52.03 tons	39.02 tons	30.35 tons
2-axle bus - Types 1, 2, & 3 	42.34 tons	33.87 tons	25.40 tons	19.05 tons	14.81 tons

Table 7.4.4. Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf.

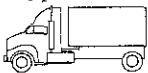
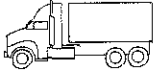
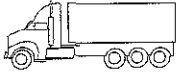

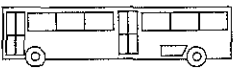
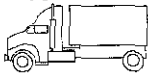
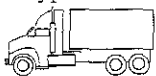


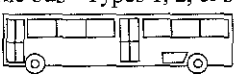
Deck Weight = 40 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	35.59 tons	28.47 tons	21.35 tons	16.01 tons	12.45 tons
3-axle truck – Type 2 	52.75 tons	42.20 tons	31.65 tons	23.73 tons	18.46 tons
4-axle truck – Type 3 	60.17 tons	48.13 tons	36.10 tons	27.07 tons	21.05 tons
5-axle truck – Type 4 	82.40 tons	65.92 tons	49.44 tons	37.08 tons	28.84 tons
2-axle bus - Types 1, 2, & 3 	40.22 tons	32.17 tons	24.13 tons	18.09 tons	14.07 tons

Table 7.4.5. Sectional Level Analysis II - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf.

Deck Weight = 50 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	33.81 tons	27.04 tons	20.28 tons	15.21 tons	11.83 tons
3-axle truck – Type 2 	50.11 tons	40.08 tons	30.06 tons	22.54 tons	17.53 tons
4-axle truck – Type 3 	57.16 tons	45.72 tons	34.29 tons	25.72 tons	20.00 tons
5-axle truck – Type 4 	78.28 tons	62.62 tons	46.96 tons	35.22 tons	27.39 tons
2-axle bus - Types 1, 2, & 3 	38.20 tons	30.56 tons	22.92 tons	17.19 tons	13.37 tons

8 GLOBAL LEVEL ANALYSIS

8.1 STRUCTURAL IDEALIZATION

At this level of analysis, a full three-dimensional structural/computer model consisting of the main span and the approach spans is to be generated (Fig. 8.1) and analyzed.

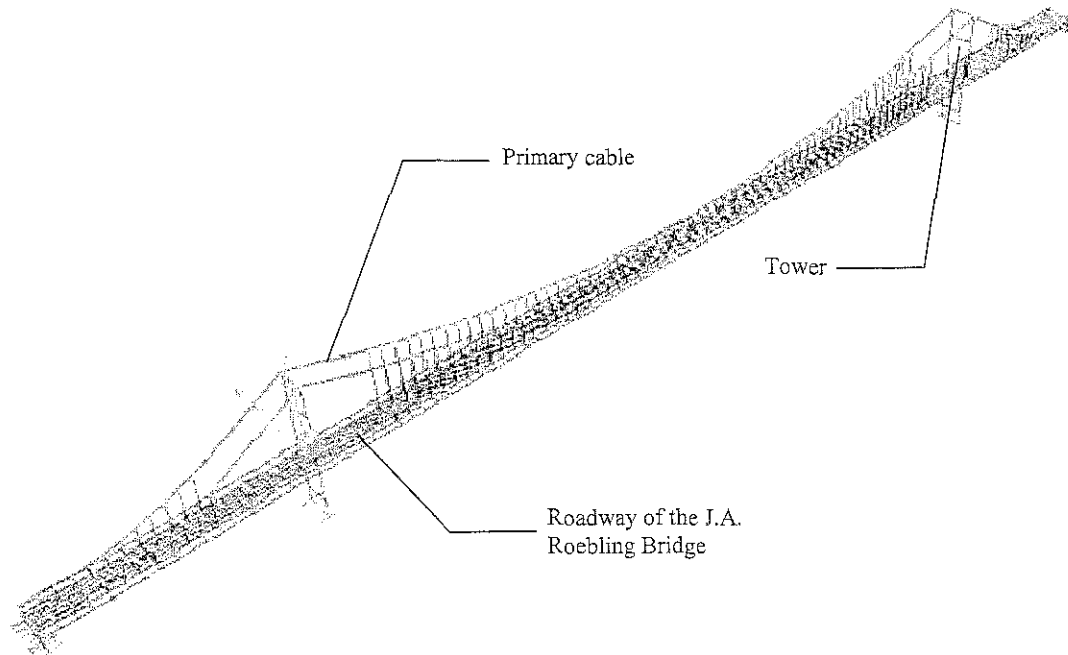


Fig. 8.1 – Structural model for Global Level Analysis.

8.2 ASSUMPTIONS

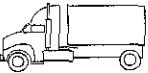
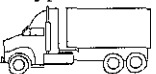


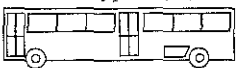
The assumptions presented in Section 3.3 are similarly applied at this level of analysis. In addition, due to the presence of different structural elements (i.e., channels, standard sections, and built-up sections) in the model, the same percent sectional loss was applied to all members.

8.3 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR TRUCKS AND BUSES

The determination of the allowable gross vehicle weight (GVW) of each truck type and bus type is determined in the manner described in section 6.3.

Similar to the element level analysis, the built-up members controls the maximum allowable GVW. The allowable GVWs for the 2-, 3-, 4-, and 5-axle trucks, and the Type 1, 2, and 3 two-axle buses, are presented in Table 8.1 for different percentages of sectional losses varying from 10% to 40%, in 10% increments.

Table 8.1. Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member.

Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	39.45 tons	31.56 tons	23.67 tons	17.75 tons	13.80 tons
3-axle truck – Type 2 	58.45 tons	46.76 tons	35.07 tons	26.30 tons	20.45 tons
4-axle truck – Type 3 	66.67 tons	53.33 tons	40.00 tons	30.00 tons	23.33 tons
5-axle truck – Type 4 	91.30 tons	73.04 tons	54.78 tons	41.08 tons	31.95 tons
2-axle bus - Types 1, 2, & 3 	44.57 tons	35.65 tons	26.74 tons	20.05 tons	15.59 tons

8.4 ALLOWABLE GROSS VEHICLE WEIGHT (GVW) FOR DIFFERENT DECK WEIGHTS

The allowable gross vehicle weights (GVWs) for the 2-, 3-, 4-, and 5-axle trucks, and the Type 1, 2, and 3 two-axle buses, are presented in Tables 8.4.1 – 8.4.5 for different percentages of sectional losses varying from 10% to 40%, in 10% increments; in addition to the different deck weights (10 psf to 50 psf in 10 psf increments). The current deck weight is 20 psf.

Table 8.4.1. Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 10 psf.

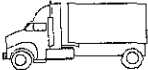
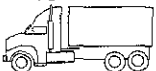
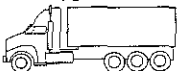


Deck Weight = 10 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	41.53 tons	24.91 tons	24.91 tons	18.68 tons	14.53 tons
3-axle truck – Type 2 	61.53 tons	49.22 tons	36.91 tons	27.68 tons	21.53 tons
4-axle truck – Type 3 	70.18 tons	56.14 tons	42.10 tons	31.58 tons	24.56 tons
5-axle truck – Type 4 	96.11 tons	76.88 tons	57.66 tons	43.24 tons	33.63 tons
2-axle bus - Types 1, 2, & 3 	46.92 tons	37.53 tons	28.15 tons	21.11 tons	16.42 tons

Table 8.4.2. Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 20 psf.





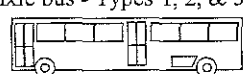
Deck Weight = 20 psf (same as Table 8.1)					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	39.45 tons	31.56 tons	23.67 tons	17.75 tons	13.80 tons
3-axle truck – Type 2 	58.45 tons	46.76 tons	35.07 tons	26.30 tons	20.45 tons
4-axle truck – Type 3 	66.67 tons	53.33 tons	40.00 tons	30.00 tons	23.33 tons
5-axle truck – Type 4 	91.30 tons	73.04 tons	54.78 tons	41.08 tons	31.95 tons
2-axle bus - Types 1, 2, & 3 	44.57 tons	35.65 tons	26.74 tons	20.05 tons	15.59 tons

Table 8.4.3. Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 30 psf.


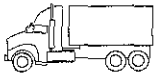
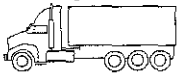


Deck Weight = 30 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	37.47 tons	29.97 tons	22.48 tons	16.86 tons	13.11 tons
3-axle truck – Type 2 	55.53 tons	44.42 tons	33.31 tons	24.98 tons	19.43 tons
4-axle truck – Type 3 	63.33 tons	50.66 tons	37.99 tons	28.49 tons	22.16 tons
5-axle truck – Type 4 	86.73 tons	69.38 tons	52.03 tons	39.02 tons	30.35 tons
2-axle bus - Types 1, 2, & 3 	42.34 tons	33.87 tons	25.40 tons	19.05 tons	14.81 tons

Table 8.4.4. Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 40 psf.

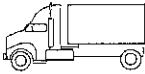
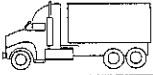
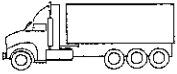
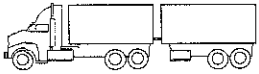
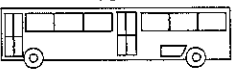
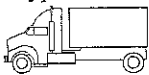
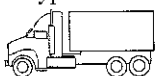
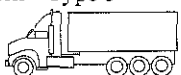


Deck Weight = 40 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	35.59 tons	28.47 tons	21.35 tons	16.01 tons	12.45 tons
3-axle truck – Type 2 	52.75 tons	42.20 tons	31.65 tons	23.73 tons	18.46 tons
4-axle truck – Type 3 	60.17 tons	48.13 tons	36.10 tons	27.07 tons	21.05 tons
5-axle truck – Type 4 	82.40 tons	65.92 tons	49.44 tons	37.08 tons	28.84 tons
2-axle bus - Types 1, 2, & 3 	40.22 tons	32.17 tons	24.13 tons	18.09 tons	14.07 tons

Table 8.4.5. Global Level Analysis - Allowable gross vehicle weight (GVW) in tons for different percentages in sectional losses in the built-up member when the deck weight equals 50 psf.

Deck Weight = 50 psf					
Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	33.81 tons	27.04 tons	20.28 tons	15.21 tons	11.83 tons
3-axle truck – Type 2 	50.11 tons	40.08 tons	30.06 tons	22.54 tons	17.53 tons
4-axle truck – Type 3 	57.16 tons	45.72 tons	34.29 tons	25.72 tons	20.00 tons
5-axle truck – Type 4 	78.28 tons	62.62 tons	46.96 tons	35.22 tons	27.39 tons
2-axle bus - Types 1, 2, & 3 	38.20 tons	30.56 tons	22.92 tons	17.19 tons	13.37 tons

9 SUMMARY AND CONCLUSIONS

The primary objective of the structural evaluation of the John A. Roebling Bridge is to determine the maximum allowable gross vehicle (truck or bus) weight (GVW) that can be carried by the bridge deck structural elements: steel grid decking, channels, standards, and/or built-up members. The John A. Roebling Bridge carries KY 17 over the Ohio River between Covington, KY, and Cincinnati, OH. A detailed evaluation of the load carrying capacity of the cables and truss elements was completed in 2003 (Report No. KTC-03-10/MS97-1F). In the present study four levels of analysis are carried out in order to capture the full load capacity spectrum:

i) Element Level Analysis

At this level of analysis, the bridge deck structural elements are analyzed independent of each other. Each element is assigned a specific tributary area, and the element support conditions are idealized as appropriate (i.e., simple, fixed, etc.).

ii) Sectional Level Analysis I

A three-dimensional structural model of the bridge deck is generated for this level of analysis. The model represents a portion of the real structure. A rule of length-to-width ratio (L/W) equal to a minimum of three (3) is applied. The width of the roadway is 31'-4". As a result, seven spans of 15'-0" each are used to produce a length-to-width ratio of slightly over three. The cable supports are idealized as simple supports.

iii) Sectional Level Analysis II

Three-dimensional models for the main span (approximately 1,100-ft in length) and the approach spans (approximately 300-ft in length each) are generated at this level of analysis. Primary cables and secondary suspenders are included in the models. The supports of the primary cables are idealized as simple supports at the towers and the end anchorages.

iv) Global Level Analysis

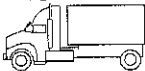
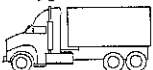



At this level of analysis, a three-dimensional model of the entire bridge is generated.

Throughout the investigation, four truck types and three bus types are considered. In 2007, the posted weight limits on the bridge were 17 tons for two-axle trucks and 22 tons for three-, four-, and five-axle trucks.

The "Element Level Analysis" yielded the critical maximum allowable gross vehicle weight (GVW) and the built-up member is the critical member.

The maximum allowable GVWs for trucks and buses are presented in Table 9.1; values presented are those obtained from the *Element Level Analysis*.

Table 9.1. Allowable Gross Vehicle Weight (GVW) in Tons for Different Percentages of Sectional Losses in the Built-Up Member

Vehicle Type	Allowable GVW (in tons) for different percentages of sectional loss				
	0% Sectional Loss	10% Sectional Loss	20% Sectional Loss	30% Sectional Loss	40% Sectional Loss
2-axle truck – Type 1 	20.17 tons	15.61 tons	11.04 tons	7.68 tons	4.80 tons
3-axle truck – Type 2 	21.52 tons	16.65 tons	11.78 tons	8.19 tons	5.12 tons
4-axle truck – Type 3 	24.09 tons	18.64 tons	13.19 tons	9.17 tons	5.73 tons
5-axle truck – Type 4 	36.68 tons	28.38 tons	20.08 tons	13.97 tons	8.72 tons
2-axle bus - Types 1, 2, & 3 	26.50 tons	20.50 tons	14.51 tons	10.09 tons	6.30 tons

* In case a % sectional loss falls between two values (e.g. 14% sectional loss), a linear interpolation between the % sectional loss that is lower and the one that is higher (e.g. 10% and 20% sectional loss) should yield adequate results.

In the event that replacement of the open grid deck will take place in the future, results are presented for different deck weights (10 psf to 50 psf, in 10 psf increments) in Chapters 5, 6, 7, and 8, respectively, in accordance with the different levels of analysis. The current open grid deck weight is 20 psf.

REFERENCES

- AASHTO, "Standard Specifications for Highway Bridge. 17th Ed. American Association of State Highway and Transportation Officials. Washington, D.C., 2002.
- AISC, "Steel Construction Manual," 13th Edition, American Institute of Steel Construction Inc., 2005.
- Ren, W.X., Harik, I.E., Blandford, G.E., Lenett, M., and Baseheart, T.M., "Structural Evaluation of The Historic John A. Roebling Suspension Bridge," Research Report (KTC03-10/MS097-1F), Kentucky Transportation Center, University of Kentucky, April 2003.